Global Acoustic Mapping of Ocean Temperatures

GAMOT

Woods Hole Oceanographic Institution
The Pennsylvania State University
Naval Research Laboratory--Stennis
The Florida State University
University of Alaska
University of Texas

QUARTERLY PROGRESS REPORT
April-June 1993

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GAMOT

July 15,1993

Dr. Ralph Alewine
Advanced Research Projects Agency
3701 North Fairfax Drive
Arlinton, VA 22203-1714

Dear Dr. Alewine,

The attached report fulfills the first quarterly progress report requirement for the period from the start of this contract to June 30, 1993 as contained in the ARPA Grant No: MDA972-93-1-0004 entitled "Real Time System for Practical Acoustic Monitoring of Global Ocean Temperature" issued by the Contracts Management Office. The United States Government has a royalty-free license throughout the world in all copy rightable material contained herein. Additional copies of this report will be mailed to the distribution list contained in Attachment Number 2 of the Grant. This report was delivered to Mr. E. Craig of RPI, Inc. for further delivery to you.

As was agreed upon at the GAMOT Executive Committee meeting held in Seattle, WA on June 6, 1993 which you attended, financial status reports will be submitted separately from this report. Woods Hole Oceanographic Institution, as the Grantee, will submit all financial reports directly to you.

The information contained in this report represents the inputs and opinions of the entire GAMOT team; Woods Hole Oceanographic Institution, the Pennsylvania State University, the Applied Research Laboratory, the Florida State University, University of Alaska, University of Texas and NRL-Stennis. If this report generates any questions, please do not hesitate to direct your questions or comments to the Principal Investigators or the Program Manager.

John L. Spiesberger	Daniel M. Frye	John M. Kenny
Principal Investigator	Principle Investigator	Program Manager
WHOI/PSU	WHOI	ARL

July 15, 1993

GAMOT EXECUTIVE SUMMARY

Work commenced on all Tasks as described in ARPA Grant No: MDA972-93-1-0004. All work is on schedule with the exception of Task D, the autonomous mooring, which is currently 45 days behind schedule awaiting the long term source description from ARPA.

• **Task A.** Work completed includes the algorithms which calculate the loss for geometric and diffracted rays. An algorithm was written which does not generate extraneous eigenrays. Work on the calculation of acoustic travel times using ocean models is also on schedule. All Task A work required to support the Task C work, SSAR development, has commenced and is on schedule.

• **Task B.** Multi-year runs of the wind driven equatorial Pacific model have been completed, allowing for the extraction of the Kelvin wave signal. Remote-forced NE Pacific (NEP) model runs have been completed for 1961-1991. Two main features appear in these calculations. 1)When realistic bottom topography is included, cyclonic eddies form on the American coast, and slowly propagate westward. 2)Kelvin waves from El Nino events produce Rossby waves with amplitude much larger than in non-El Nino years and therefore should significantly effect acoustic travel times. Algorithms for calculating the travel time from acoustic source to receiver have been developed for great circle paths. Preliminary estimation of travel time anomaly due to variations in upper layer thickness are comparable to observations. A thorough study of this commences this quarter.

• **Task C.** All elements of the SSAR development are well underway and moving smoothly towards the September 1993 prototype tests. The array design (spacing and number of hydrophones) is complete, as is the optimum depth determination.

• **Task D.** Work is on hold and cannot commence until the long term source specifications are provided.

• **Meetings.** The first Executive Committee meeting was held on June 6 in Seattle followed by the ARPA Program review on June 7. Informal program reviews were held at WHOI on May 20 and July 1. The next Executive Committee meeting is scheduled for September 15 at WHOI and will be followed by the Program Review on September 16-17 which GAMOT is hosting.

• **Outside Interest.** GAMOT's program was described in various press articles, the most notable of which were the short articles contained in *Business Week* and *International Business Week*. The status of the program was briefed to various offices at ONR and the Oceanographer of the Navy.

• **Issues and Concerns.** There are two issues:

-Lack of source specifications for the autonomous mooring.

-Acoustic interaction of cabled sources with the bottom slope on which they are mounted.

TASK A
TOMOGRAPHIC DATA ANALYSIS

All Task A work is on schedule.

We wrote computer programs to help us quantitatively examine the tradeoffs of placing the subsurface element of the SSAR at different depths. Based on these simulations, this depth was selected to be at 500 m. As discussed in the Task C section, computer programs were also developed to determine the optimal number of array elements was well as element spacing.

Work on the development of the SSAR signal processing software is progressing smoothly and is on schedule.

We wrote computer programs to calculate the travel times of sound through ocean models. Variations in the speed of sound are calculated from model layer displacements using (6.11.17) from Atmosphere Ocean Dynamics (Gill 1982). These programs will be used to compare with travel time data collected by Spiesberger in the 1980's. This work in being done in conjunction with Task B.

Source location chosen by ATOC and the associated bottom interaction problems may cause a problem for the SSARs. This potential problem is discussed in detail in the Issues and Concerns section.

GAMOT published five scientific papers and submitted one manuscript to a journal in support of the ARPA program.

Tidal signals in acoustic transmissions need to be accounted for and removed, if possible, to better detect climatic changes in the ocean's temperature. The first study of tidal signals in basin-scale acoustic transmissions found that barotropic models of tides are often inadequate for predicting the change in acoustic travel time (Headrick, Spiesberger, and Bushong, 1993). We found that a baroclinic model for the tides must often be added to barotropic model of tides to account for tidal signals in the acoustic travel times. Within 100 km of seamounts, and other bathymetric features, internal tides are generated by the barotropic tidal currents. The internal tides move the water vertically and the associated temperature variations change the acoustic travel time by as much as plus or minus .02 seconds due to the barotropic tidal currents. We discovered some of these internal tides generated by guyots in the Moonless Mountains. We also estimated that the world's seamounts account for about 4% of the dissipation of barotropic tidal currents at the principal lunar semi-diurnal tidal period. In the context of GAMOT's program, tides will not present any major obstacles for mapping ocean temperatures with autonomous moorings with sources or with the SSARs.

An accurate algorithm for the speed of sound in seawater is important for estimating the ocean's temperature with sound. Two years ago, Spiesberger and Metzger, using acoustic tomography, discovered that the international standard

algorithm for sound speed was too fast at depths below 1 km. Present analysis indicates that another algorithm based on Del Grosso's work is more correct than the international standard algorithm (Spiesberger, 1993).

Ray trace algorithms are used to predict where the sound went in the ocean prior to using inverse techniques to map climatic temperature changes in the ocean. We have written a new ray trace program which removes spurious arrivals and can thus be automated for mapping ocean temperatures in near real time (Bowlin, Spiesberger, Duda, and Freitag, 1993). This is the first program we are aware of that automatically generates reliable predictions for the multipaths in cases of sound speed varying with depth and range and in cases where the bottom depth is not constant. The agreement is excellent between data and predictions from this new program for a 3000 km section in the northeast Pacific (Spiesberger, Terray, and Prada, 1993).

One paper was published describing the cost advantages of monitoring global ocean temperatures with sound using GAMOT's SSAR and autonomous source mooring (Spiesberger, 1993). This is the first study of the economics of deploying acoustic tomography instruments for mapping ocean temperatures. The analysis indicates that GAMOT's instruments will map ocean temperatures about eight times cheaper than possible with sources and receivers cabled to shore. Even if these cost estimates are imperfect, GAMOT's instruments will undoubtedly be less expensive than cabled systems.

A paper was published describing a new telemetry scheme to remove travel time variations in real time caused by wander of an acoustic source attached to an autonomous mooring (Spiesberger and Bowlin, 1993). The scheme is robust and does not require any battery energy over and above that expended in past tomography experiments. The paper describes how both the horizontal and vertical positions of the source are telemetered to fixed or drifting receivers. The GAMOT group will test this scheme as part of Task D.

During the next quarter, we expect to accomplish the following scientific milestones:

- Data processing algorithms for the SSAR.
- Determine if Dr. Fred Tappert's Parabolic algorithm is suitable for calculating acoustic travel time from basin to global scales in the ocean. Dr. Tappert will be working with Dr. Spiesberger at Penn State this summer.
- Start work on the forward modeling from Spiesberger's 1987 basin scale transmissions in the Pacific. This work leads toward an analysis of the seasonal cycle in the northeast Pacific.
- Start work on integrating our new ray trace program in Cornuelle's existing inverse program.

Figure:
A.1 Task A Schedule

NUM	TASK A	Start Date	Finish Date
A1	ESTIMATE IMPROVED RESOLUTION FROM SSAR BY NUMERICAL SIMULATION	1/15/94	1/15/95
A2	DETERMINE THE OPTIMUM :		
	SSAR ARRAY DEPTH	5/1/93	6/30/93
	SOURCE LOCATION AND DEPTH	5/1/93	11/30/93
A3	ESTIMATE THE INFLUENCE OF FREQ, INCLINATION, DISTANCE AND SVP ON MULTIPATH STABILITY	5/1/93	6/30/95
A4	DEVELOP ALGORITHMS AND COMPUTATIONS WHICH:		
	DO NOT GENERATE EXTRANEOUS EIGEN RAYS	5/1/93	5/15/93
	CALC LOSS FOR GEOMETRIC RAYS	5/1/93	5/15/93
	CALC LOSS FOR SHADOW ZONES OF CAUSTICS	5/1/93	5/15/93
A5	INCORPORATE THE RAY TRACE ALGORITHM INTO THE INVERSE PROGRAM	7/15/93	5/15/94
A6	ASSIMILATE TOMO DATA INTO O'BRIEN OCEAN MODEL	9/15/94	4/1/95
A7	AUTOMATE THE PROCEDURE TO CHANGE SPATIAL COORDS OF MULTIPATHS DUE TO SEASONAL CYCLE	5/1/93	6/30/95
A8	DEMO REAL TIME TOMOGRAPHY:		

Figure A.1

NUM	TASK A	Start Date	Finish Date
	USING DATA FROM SSAR	1/15/95	6/30/95
	USING DATA FROM FIXED RCVRS	3/15/95	6/30/95
A.9	ANALYSIS OF 1987 TOMO DATA TO DETERMINE SEASONAL CYCLE INFLUENCES ON ACOUSTIC		
	FORWARD PROBLEM	7/15/93	6/30/94
	INVERSE PROBLEM	9/15/93	8/30/94
A.10	SIMULATION OF OCEAN CLIMATE TEMPS FROM AN O'BRIEN OCEAN MODEL USING SSARS	5/1/94	5/30/95

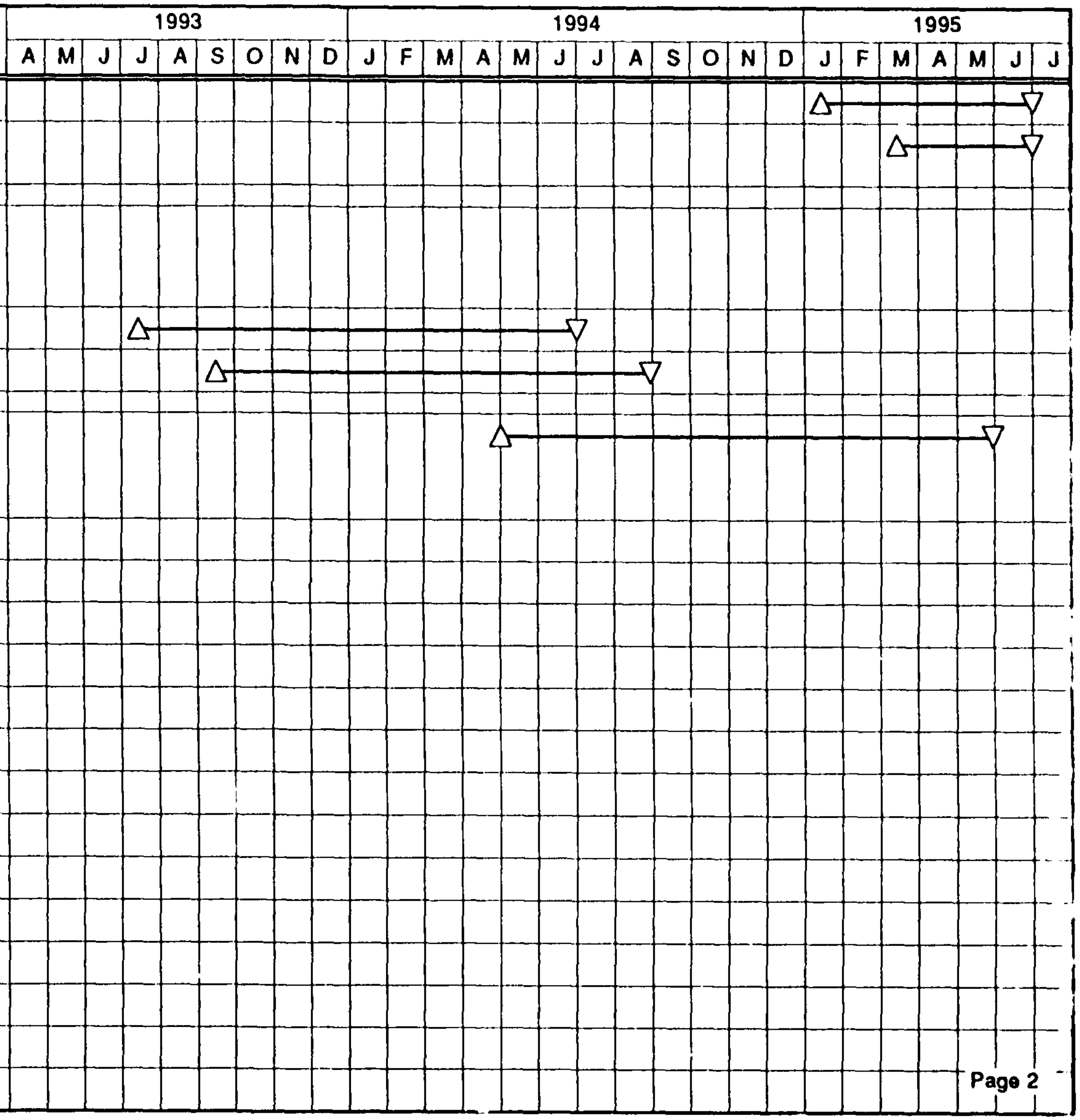


Figure A.1

TASK B
OCEAN MODELING

We have completed running a two layer model of the equatorial Pacific from 20S to 25N and 120W to 75E with a spatial resolution of 1/12 degree (1/6 between like variables) and time steps of 20 minutes. The model includes realistic land and bottom topography at resolutions of 1/6 degree. The model was initialized with a 20 year "spin up" driven by climatological winds. The Florida State University winds were then applied for 1961-1991 and the coastal Kelvin signal was extracted. That is, the upper layer thickness (ULT) at the easternmost point in the Pacific Ocean that overlaps the southern border of the NE Pacific (NEP) model is recorded.

The NEP model has the same resolution as the equatorial model, but with a time step of 10 minutes. The forcing is remote, being driven at the south-easternmost point using a Kelvin wave constructed from the height record of the equatorial model. The zonal structure of the incoming Kelvin signal is simulated with an exponential envelope decaying from the forced location. There is no spin-up in these experiments.

Typical ULT variations in the NEP model are 15 m (compared to a mean depth of roughly 150 m) with maximum due to El Nino events with ULT changes of 50 m (see figure B.1). Stable cyclonic eddies form around 28N and 40N and slowly propagate westward. These are more clearly seen than when the climatological Kelvin signal is used to drive the NEP model.

Preparations have been made to compare observed changes in acoustic travel time with predictions based on changes in ULT in our NEP model. New software has been written and validated that extracts the ULT along great circle paths. Total travel times from acoustic sources to receivers along the great circle paths are estimated using a sound speed estimate (Roed 1993)

$$c = c_0 - \beta \Delta\rho (\alpha \Delta)^{-1} (h-H)$$

where c_0 is the mean sound speed, β is the local derivative of the Coriolis term, $\Delta\rho$ is the density difference between upper and lower layer, α is a thermal expansion coefficient, Δ is a geometric constant, h is the upper layer thickness (ULT), and H is its mean thickness. Travel time is then

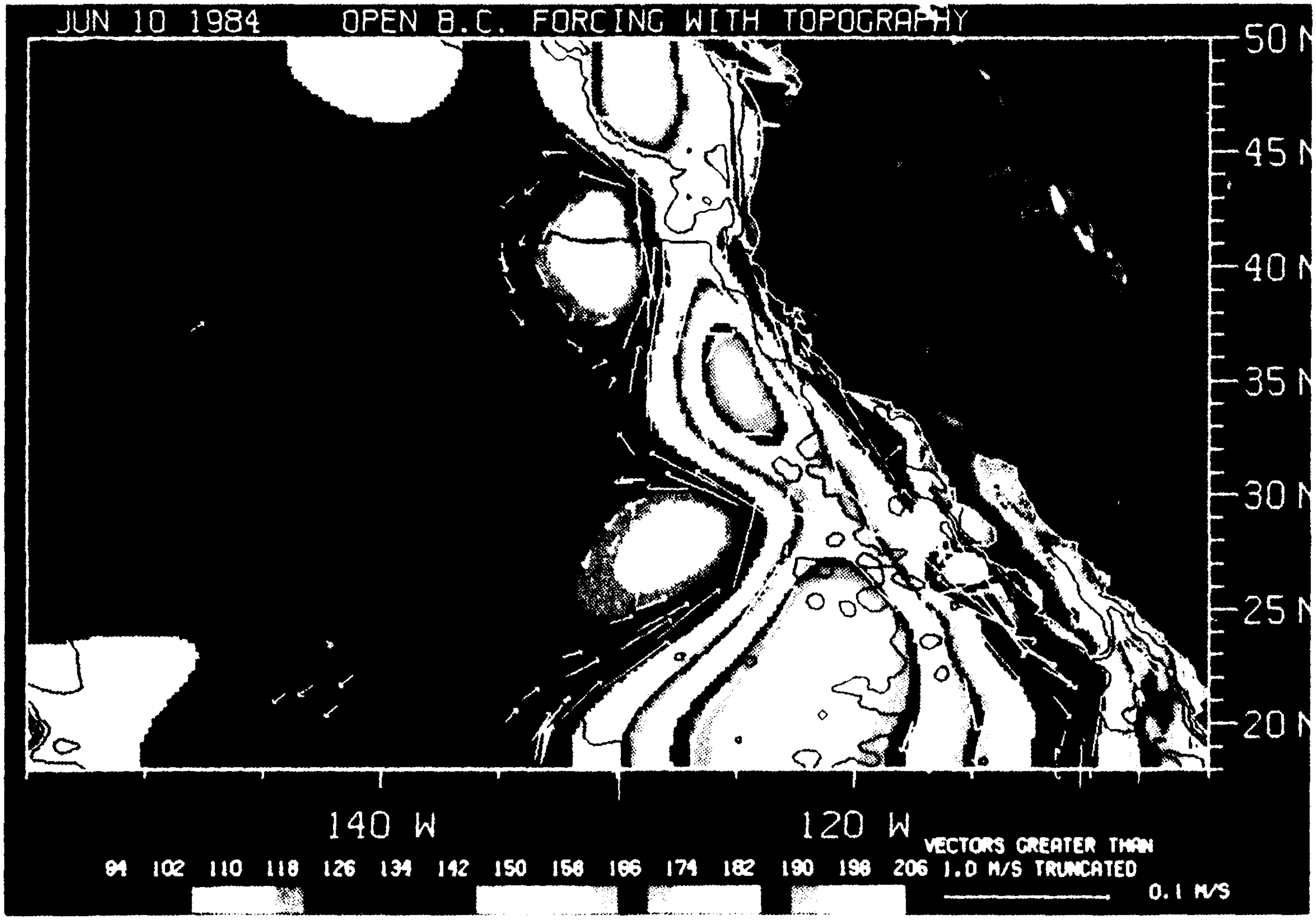
$$T = \int c^{-1} \, ds$$

where ds is the segment along the great circle path from source to receiver.

Using the results of our modeling efforts, estimates of T (travel time) can now be made for any observation taken during the integration period 1961-1991. This will allow direct comparison of estimated and measured T and this comparison will commence this quarter.

Work in this quarter will also involve comparing influences of wind-driven and remote-forced ULT anomalies in the NEP results. We hope to demonstrate that changes in travel times result from changes induced in the ULT by equatorial signals, with only a small contribution from locally forced wind-driven structures.

Figures:
B.1 ULT Variation due to El Nino color graph
B.2 Task B Schedule



JUN 10 1984
OPEN B.C. FORCING WITH TOPOGRAPHY
50 N
45 N
40 N
35 N
30 N
25 N
20 N
140 W
120 W
94 102 110 118 126 134 142 150 158 166 174 182 190 198 206
VECTORS GREATER THAN
1.0 M/S TRUNCATED
0.1 M/S

Jul 14, 1993

NUM	TASK B	Start Date	Finish Date
B.1	OBTAIN EQUATORIAL PAC WIND FIELDS FROM 80-91 AND DRIVE THE EQUATOR MODEL	4/14/93	5/31/93
B.2	EXTRACT THE COASTAL KELVIN SIGNAL FROM THE EQUATOR MODEL AND DRIVE THE MID LATITUDE MODEL	6/1/93	6/30/93
B.3	INTEGRATE THE MODEL SOLUTIONS BETWEEN HAWAII AND WEST COAST RCVRS	6/1/93	6/30/93
B.4	COMPARE WITH OBSERVATIONS AND IDENTIFY VARIABILITY IN ACOUSTIC TRAVEL TIMES	7/1/93	9/1/93
B.5	DESIGN FUTURE EXPERIMENTS	9/15/93	4/1/94
B.6	ADD MODEL COMPLEXITY AND VERTICAL STRUCTURE TO IMPROVE ESTIMATES OF TRAVEL TIME	4/15/94	9/1/94
B.7	RUN NRL MODELS	9/15/94	4/1/95
B.8	USE REAL DATA TO ASSIMILATE INTO OCEAN MODELS OF THE NORTH PACIFIC	9/15/94	4/1/95
B.9	SUBMIT FINAL REPORT	4/15/95	6/30/95

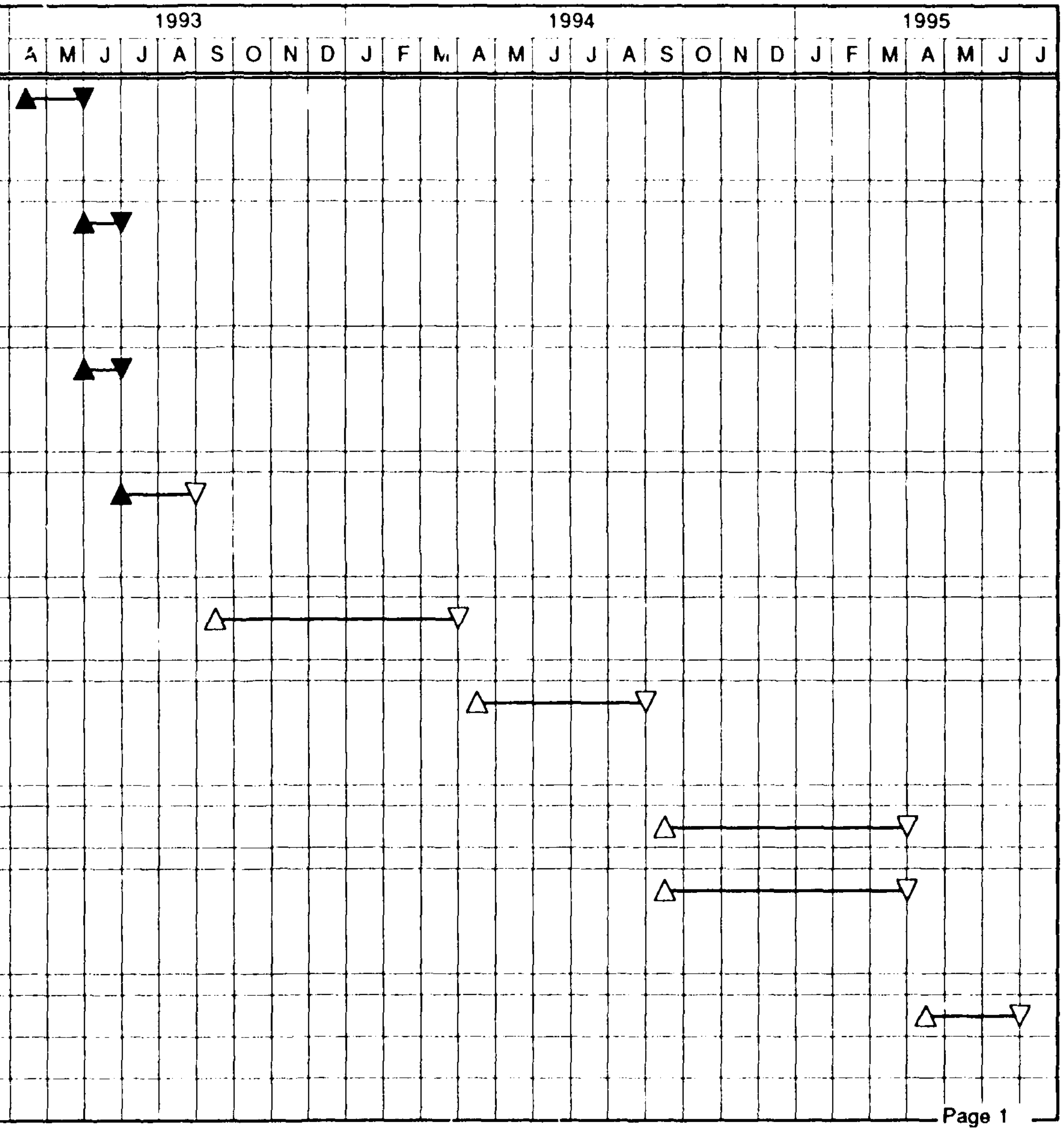


Figure B.2

TASK C
SSAR DEVELOPMENT

Three prototype SSAR mechanical designs have been developed. They are:

- •Option One: the ***Snubber***
- •Option Two: the ***Standard,*** and
- •Option Three: the ***Cobra.***

The first two options are the most promising and component procurement and fabrication of these designs has commenced. The third option will be fabricated only if the first two options fail to perform as expected. Accelerated life testing of key components has been delayed pending delivery of rubber hoses and electromechanical cable and has been rescheduled for the end of August.

The design of the prototype SSAR instrumentation system is also underway. This design includes instrumentation to measure the forces on key components, to monitor the motion and attitude of the surface buoy and the acoustic array, and to monitor system performance in a variety of sea conditions. Data collected during the prototype sea trials will be recorded in situ with some data telemetered by ARGOS satellite.

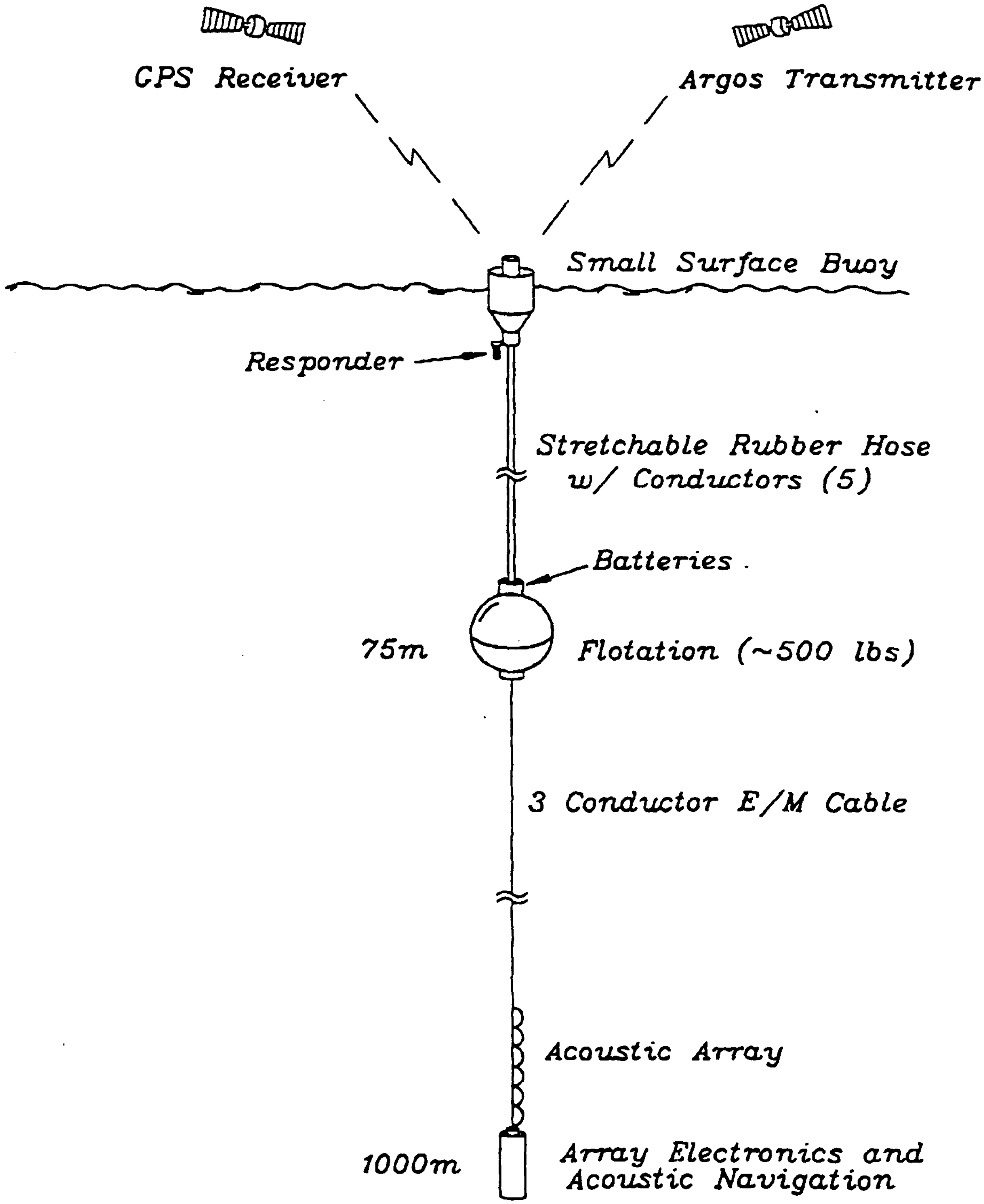
Final design of the electronic system for the operational SSARs is nearing completion. Designs for the surface buoy electronics package, GPS system and ARGOS system, the array processing system, the battery power supplies, and the inter-module communications links have been completed. Design work continues on the acoustic navigation system and the acoustic data processor software. Testing of these electronic subsystems will begin this quarter.

Based on computer simulations, the tradeoffs of placing the SSAR acoustic array at different depths was quantitatively examined and an array depth of 500 m was determined to be optimal. Computer programs were also developed to help design the number and spacing of the array elements. Based on this analysis, a six element array of approximately 53 m length was selected. This array design provides two advantages over a single element receiver. First, the signal-to-noise ratio is improved with beamforming. Second, the vertical arrival angle of each multipath can be estimated, thereby adding confidence to the identification of the multipaths.

A computer program, **DXMOOR** , was developed to calculate the drift speed, the shape and the stress distribution, from top to bottom, of free drifting instrumented lines immersed in ocean currents. The SSARs' reactions to shear currents were investigated with this program and the results used to design the surface flotation of the ***Snubber*** and ***Cobra*** options.

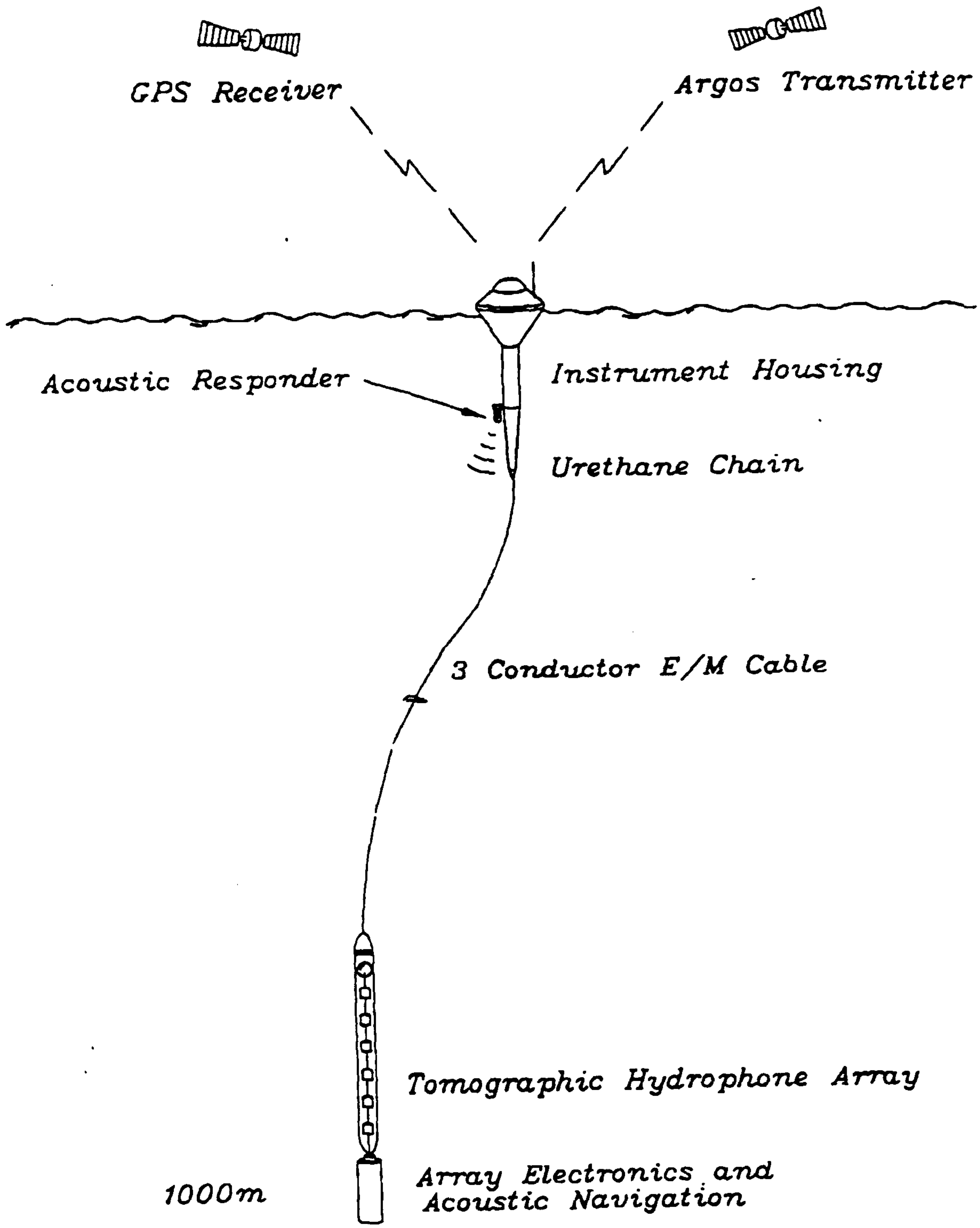
At-sea testing of the SSAR prototypes begins with a one week deployment offshore Bermuda beginning about September 13 followed by retrieval about September 20. A second short deployment is planned for about October 24 with retreival about November 3. A long term test will begin in the Pacific following the

short term tests. The schedule for the long term test will be developed this quarter.



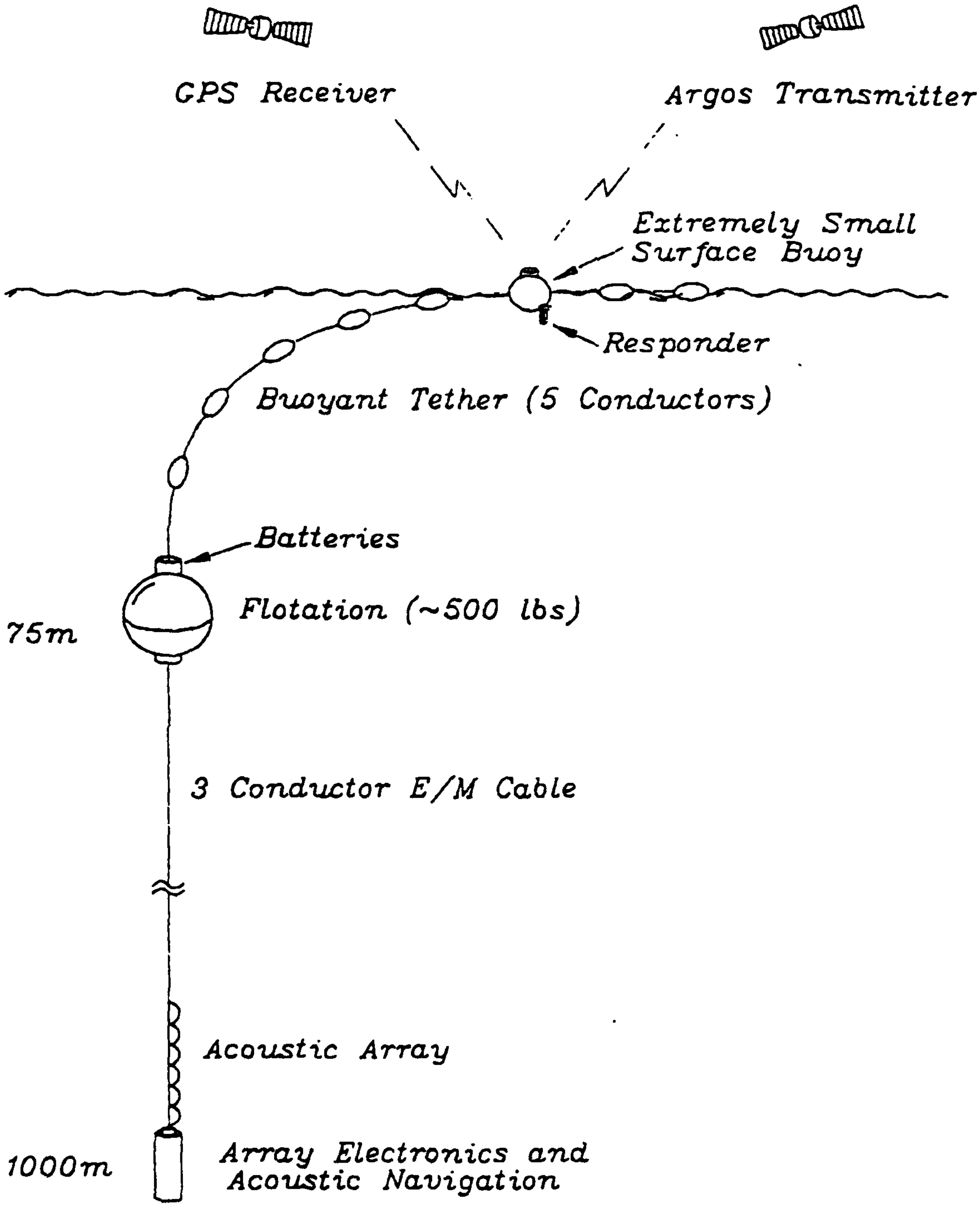
"Snubber" SSAR design

Figure C.1



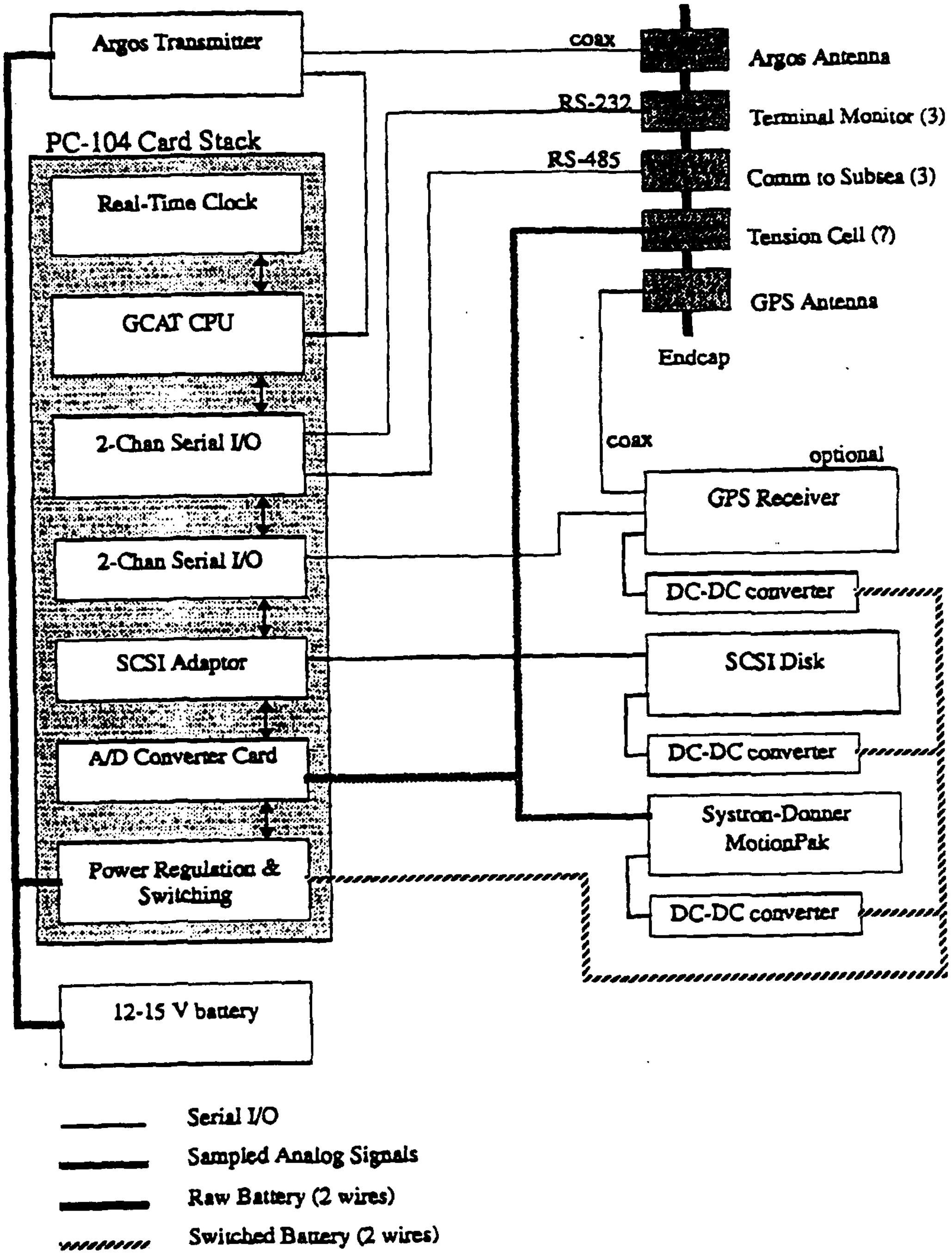
"Standard" SSAR design

Figure C.2



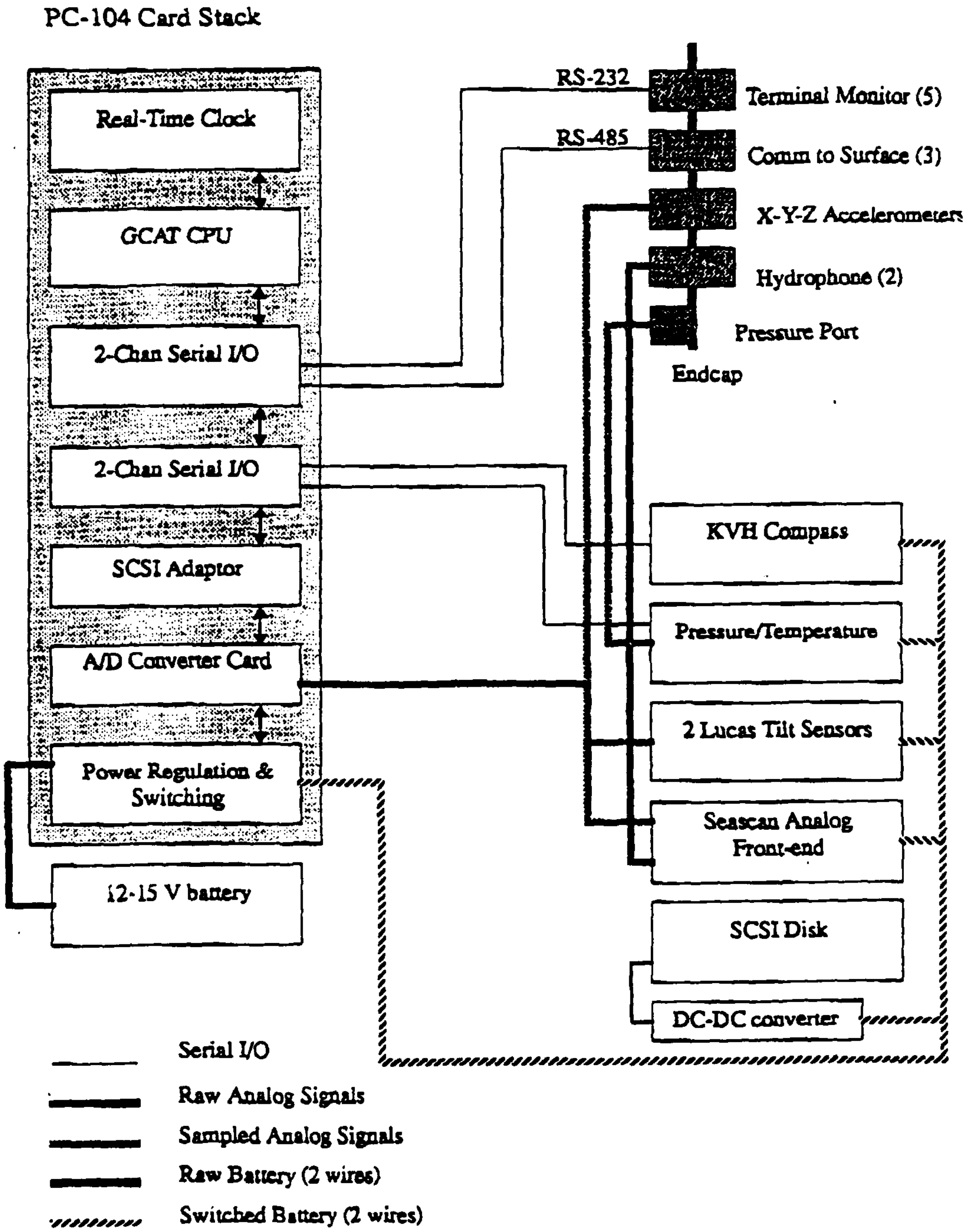
"Cobra" SSAR design

Figure C.3



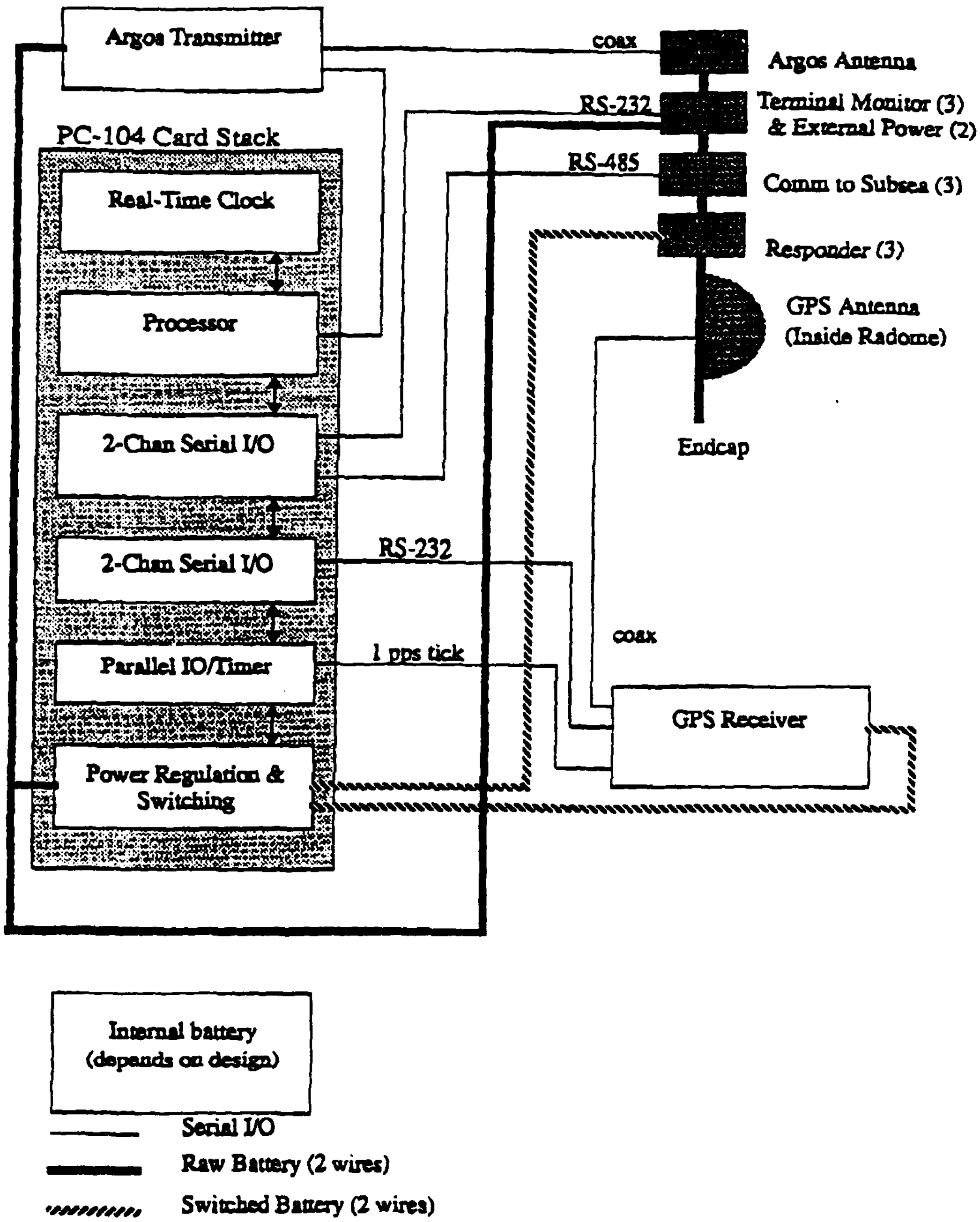
Test buoy surface system electronics block diagram

Figure C.4



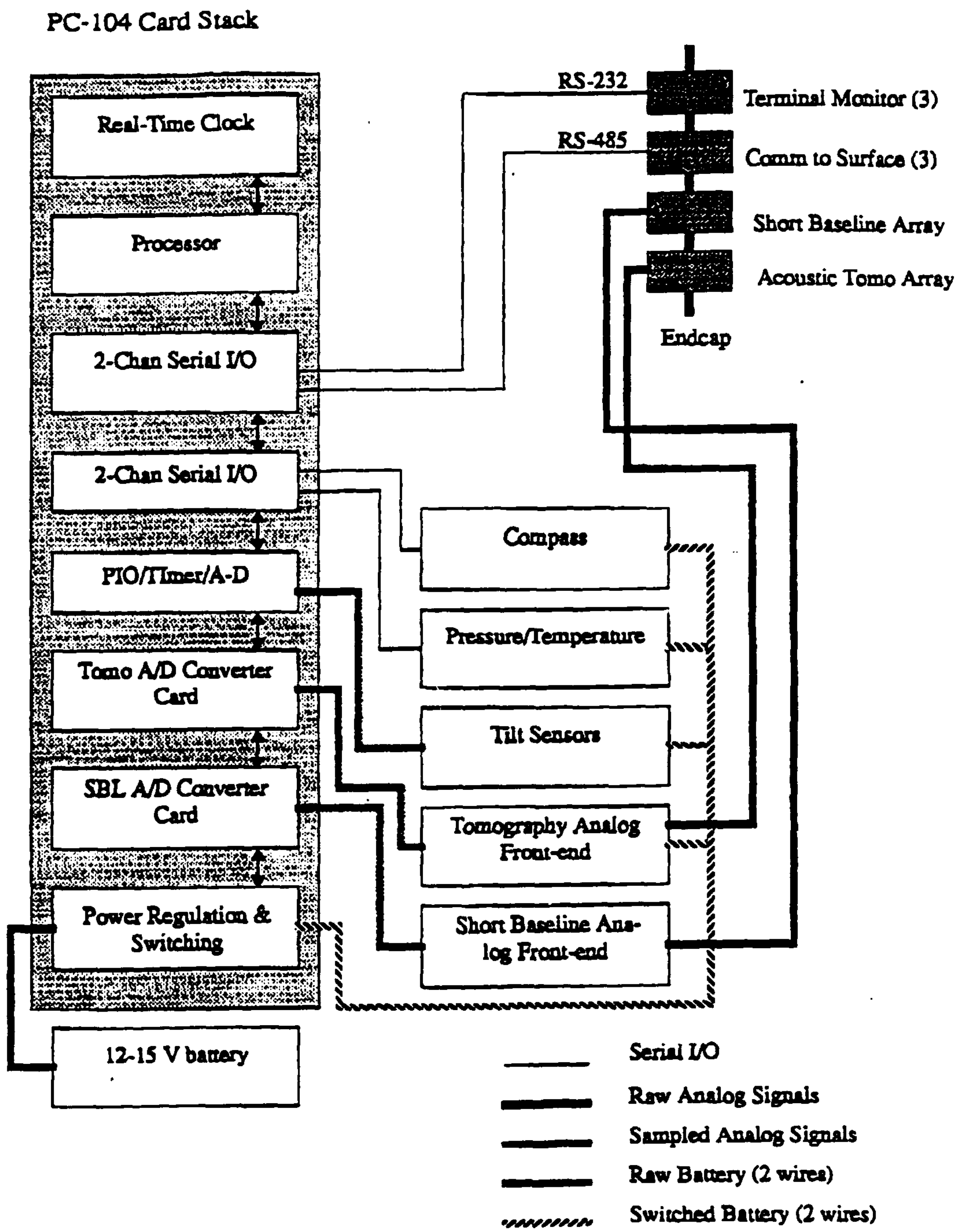
Test buoy bottom electronics block diagram

Figure C.5



Surface system electronics block diagram

Figure C.6



Subsurface system electronics block diagram

Figure C.7

Jul 14, 1993

NUM	TASK C	Start Date	Finish Date
C.1	MECHANICAL DESIGN OF CABLE, BOUY AND TERMINATIONS		
	INITIAL DESIGN	4/15/93	8/9/93
	ACCEL LIFE TESTS	8/31/93	10/31/93
	AT SEA TRIALS	9/13/93 1/15/94	10/27/93 1/15/95
	DESIGN REFINEMENTS	3/1/94	3/1/95
C.2	BOUY ELECTRONICS AND NAV SYSTEMS		
	SYSTEM DESIGN	4/15/93	9/1/93
	CONTROLLER /GPS INTERFACE	4/15/93	12/15/93
	ARGOS TELEMETRY	4/15/93	12/15/93
	POWER SYSTEM	4/15/93	12/15/93
	PROTOTYPE TESTS	8/1/93	3/1/94
C.3	DSP SYS ACOUSTIC NAV AND SENSOR MODULE		
	SYSTEM DESIGN	4/15/93	9/1/93
	SENSOR MODULE	4/15/93	12/15/93
	ACOUS NAV MODULE	4/15/93	12/15/93
	DSP MODULE	4/15/93	3/1/94
	DSP SOFTWARE	5/23/93	12/15/93
	TELEMETRY	4/15/93	12/15/93
	PROTOTYPE TESTS	8/1/93	3/1/94
	DESIGN REFINEMENTS	3/1/94	3/1/95

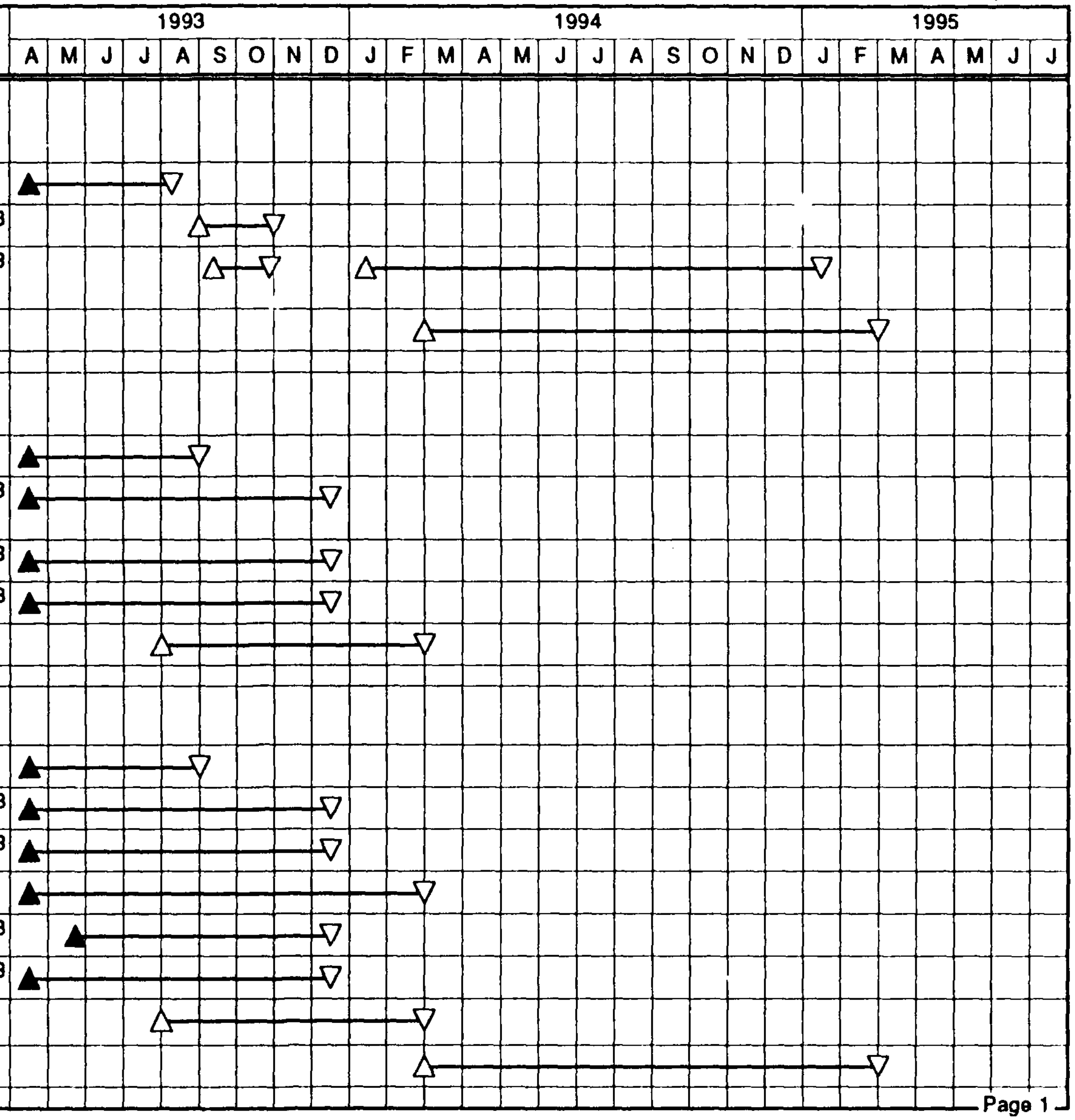


Figure C.8

Jul 14, 1993

NUM	TASK C	Start Date	Finish Date
C.4	HYDROPHONE ARRAY		
	ARRAY DESIGN	4/15/93	6/10/93
	PROTOTYPE TESTS	10/1/93	3/1/94
C.5	GPS NAV SA CORRECTIONS		
	DATA COLLECTION METHODS	4/15/93	8/1/93
	DEVELOP SOFTWARE	5/1/93	12/15/93
	PROTOTYPE TESTS	12/15/93	3/1/94
C.6	SYSTEM INTEGRATION		
	LAB TESTS	11/15/93	1/30/94
	AT SEA TEST	2/18/94	2/22/94
	DESIGN REFINEMENTS	2/25/94	9/1/94
C.7	FABRICATION OF SSAR		
	BUILD 2 PROTOTYPES	5/1/93	8/30/93
	BUILD & TEST 3 SSARS	1/1/94	4/30/94
	BUILD & TEST 3 SSARS	3/1/94	6/30/94
	BUILD & TEST 4 SSARS	5/1/94	8/30/94
C.8	FIELD OPERATIONS		
	DEPLOY 3 SSARS	5/1/94	5/30/94
	DEPLOY 3 SSARS	7/1/94	7/30/94
	DEPLOY 4 SSARS	9/1/94	9/30/94

Timeline: 1993 (A M J J A S O N D), 1994 (J F M A M J J A S O N D), 1995 (J F M A M J J)

Figure C.8

TASK D
THE AUTONOMOUS MOORING

The autonomous mooring work has been delayed until an appropriate source can be identified as the source to be used on the mooring. Key questions that need to be answered before significant work can be done on this task include:

- Source size and weight
- Source depth limitations and pressure compensation volume
- Specifications of the power amplifier
- Specifications of the input waveform
- Source efficiency, power output, MTBF
- Any other important considerations such as duty cycle allowable, temperature concerns, warm-up time, cooling requirements, vibration/shock specifications, etc.

Our understanding is that the long term source being developed under the ATOC program was envisioned as an appropriate source for the autonomous mooring by ARPA. It has become clear, following our June program meeting in Seattle, that the long term source will not be available in time to meet our schedule for Task D. To meet our schedule we need to have a source in hand by the end of 1993. Unfortunately, the ATOC source will not be available until the end of 1994 at the earliest.

We have examined several alternate solutions to this problem and these solutions are presented for consideration in the Issues and Concerns section of this report.

Figures:
D.1 Task D Schedule

Jul 13, 1993

NUM	TASK D	Start Date	Finish Date
D.1	SOURCE ELECTRONICS		
	DEVELOP TRANSMITTER	9/15/93	2/15/94
	INTEGRATE NAV AND CLOCK	9/15/93	2/15/94
	PROTOTYPE TESTS	2/15/94	7/15/94
	AT SEA TEST	8/15/94	9/1/94
D.2	SURVEY SYSTEM		
	DEVELOP SURVEY SYSTEM	9/15/93	2/15/94
D.3	MOORING DESIGN		
	ASSESS 70 HZ IMPACT	6/1/93	9/15/93
	DESIGN MOOR	10/15/93	2/15/94
	FABRICATE MOOR	2/15/94	7/15/94
D.4	PRESSURE COMP SYSTEM		
	DEVELOP SYSTEM	10/15/93	7/15/94
	LAKE SENECA TESTS	7/15/94	8/1/94
	AT SEA TEST	8/15/94	9/1/94
D.5	OPERATIONS		
	DEPLOY SOURCE	10/1/94	10/30/94
	MAINT CRUISE	2/1/95	2/28/95
	RETRIEVAL CRUISE	5/1/95	5/30/95
D.6	LONG TERM SOURCE		
	PROVIDE INPUT	6/1/94	6/30/95

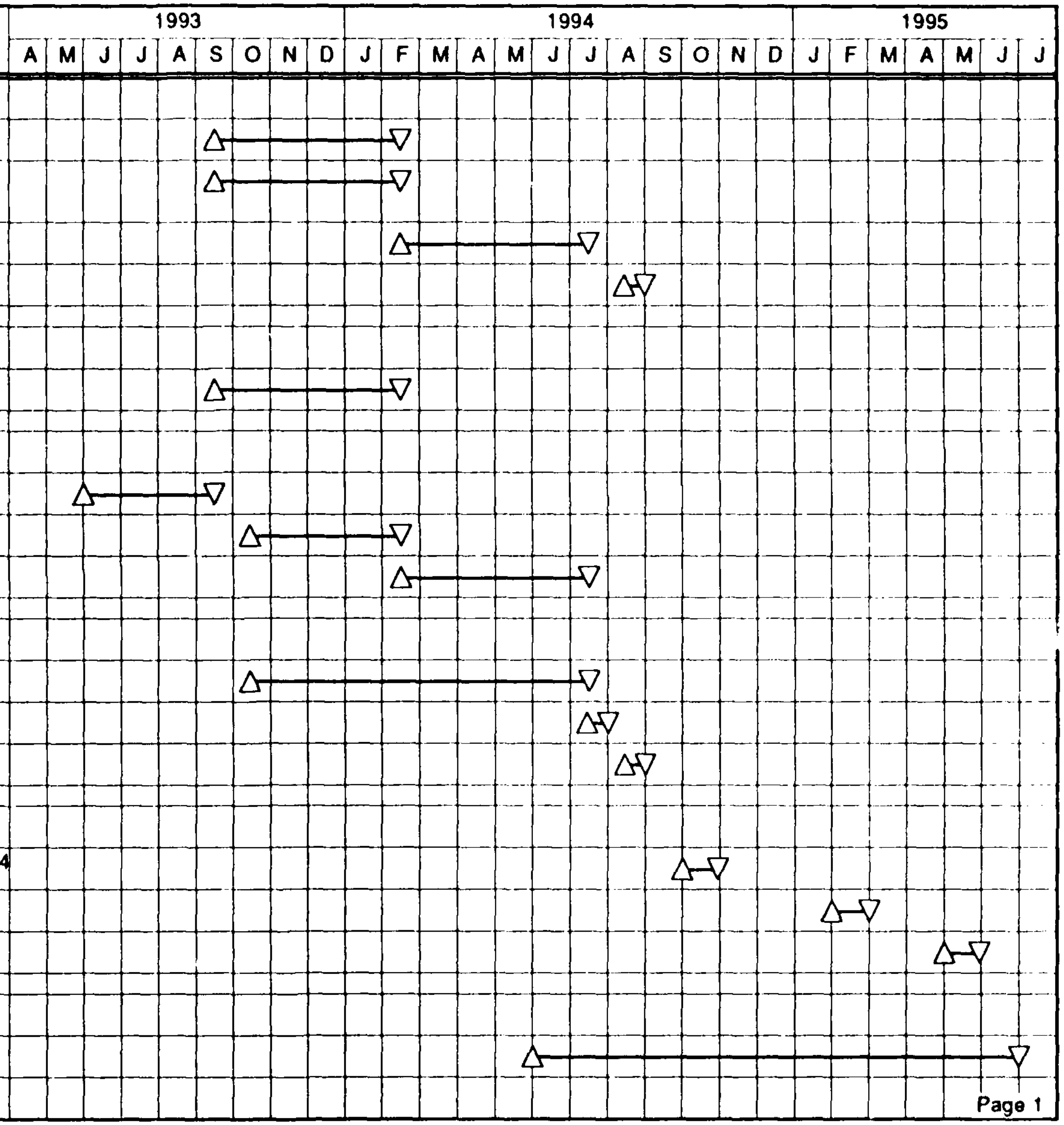


Figure D.1

ISSUES AND CONCERNS

There are two issues which will be addressed in this report. They are:

- Acoustic interaction of cabled sources with the bottom slope on which they are mounted.
- Lack of source specifications for the autonomous mooring.

CABLED SOURCES ON THE BOTTOM

The principal concern is related to that fact that the program sources will in all likelihood have transmissions influenced by local acoustic interactions with the bottom slope on which they are mounted. In January 1993, it was agreed that the program sources would be placed on slopes of about 18 degrees to avoid bottom interaction difficulties. However, it was revealed at the June Program Progress Meeting in Seattle that source locations on slopes of less than 18 degrees are now being considered.

Bottom interaction is or may be a major problem for SSARs because the transmission path changes for each different SSAR position and the bottom interaction is typically not known well enough to accurately predict its effects. Bottom interactions are not as much of a problem for fixed receivers because the changes in travel time are unaffected by interactions with the bottom.

Even if bottom mounted sources are placed on 18 degree slopes, that slope is only 18 degrees in a direction straight out from the slope. At bearing angles perpendicular to that direction, the effective bottom slope is 0 degrees. Thus, bottom mounted sources are not the most effective way to insonify a wide sweep of bearing angles into the ocean and avoid bottom interactions.

One solution is to locate sources where they are free from bottom interaction problems. Autonomous moorings for acoustic sources can solve this problem and offer several advantages over cabled sources:

- Moored autonomous sources are free from any local bottom interaction aberrations.
- Moored autonomous sources can be placed away from islands so they insonify a 360 degree sweep without blockage by local islands. In other words, instead of installing two cabled sources on both sides of an Hawaiian Island to insonify the North and South Pacific, one moored source can be placed to project into the entire Pacific.
- Moored autonomous sources can be deployed from standard research vessels and do not require cable laying ships.
- These three advantages of moored autonomous sources may offer tremendous cost savings over cabled sources in some situations.

Moored autonomous sources have the potential to operate for two years between servicing as demonstrated by the efficiency of the Slavinsky and Bogolubov's electronic sources. These sources were successfully tested by members of the GAMOT group in 1992. This 225 Hz source has an efficiency of about 50% and

has the desired source level. In principal, this source could be made to operate at 70 Hz with similar efficiency characteristics.

IDENTIFICATION OF A SOURCE FOR THE AUTONOMOUS MOORING

As discussed in the Task D Section, the autonomous mooring work is being delayed because an appropriate source has not been identified for the mooring and the long term source may not be appropriate and will not be available until well after it is needed to complete this important aspect of GAMOT's work prior to June 30,1995.

We would like to suggest several alternatives:

1. Utilize an existing higher frequency source such as an HLF-5 or a Slavinsky source to demonstrate the concept. This would require some modification to the SSAR processing software and hardware, but would provide a more rigorous test of the drifting receiver concept than the lower frequency source. The Navfac stations would not need modifications.
2. Commission the fabrication of a 70 Hz source suitable for use on a mooring. Slavinsky may have a suitable candidate. This would have to be done quickly to meet our schedule, but would offer the advantage of providing the program with a second candidate source (specifically designed for moored applications) for the follow on program.
3. Modify an existing source for 70 Hz operation. This is not attractive for several reasons:
    - The existing source (HLF-6) is inefficient and not well suited for battery powered operations.
    - It would be difficult to pressure compensate and the engineering effort would be wasted since future 70 Hz sources would not use this compensation system, and
    - The HLF-6 has demonstrated less than adequate reliability.

Alternative 2 is the best choice if cost and schedule constraints can be met. Alternative 1 can be accomplished in the least time, at the least cost, and with the least risk. A decision as to which alternative to pursue needs to be made in the near future.

DELIVERABLES

One deliverable was due and it was delivered this quarter:

• The statement of completion of the 1980-1991 equatorial wind field model.

There are three deliverables due at the end of this quarter:

• Extract the coastal Kelvin signal from the equatorial model and drive the mid-latitude model from 1980 to 1990 and provide a video of the solution.

• Integrate the model solutions between Hawaii and the West Coast and provide a graph of travel time difference as a function of time and great circle paths.

• Deliver two prototype SSARs.

Figure:
GAMOT Deliverable Master Schedule

GAMOT DELIVERABLE MASTER SCHEDULE

Jul 15, 1993

TASK	DELIVERABLE	Start Date	1993							1994												1995							
			J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
A.1	SOURCE DEPTH, FREQ, LOCATION AND TYPE RECOMMENDATION	11/30/93						◇																					
A.2	RANGE OF ACCEPTABLE SSAR DEPTHS	11/30/93						◇																					
A.3	SIGNAL PROCESSING OF SSAR SIGNAL	6/30/95																									◇		
A.4	ARRAY MOTION COMPENSATION SOFTWARE	3/30/94										◇																	
A.5	SEASONAL MULTIPATH ALGORITHMS	6/30/95																									◇		
A.6	ARGOS RECEPTION ERROR STUDY	6/30/95																									◇		
A.7	ALTERNATIVE SATELLITE SYSTEM EVALUATION	6/30/95																									◇		
A.8	REAL TIME TOMOGRAPHY ALGORITHMS	6/30/95																									◇		
A.9	NEW WORK: SEASONAL CYCLE INFLUENCES ON ACOUSTIC TRAVEL TIMES BASED ON ANALYSIS OF 1987 TOMO DATA	8/30/94															◇												
A.10	NEW WORK: OCEAN MODEL OF TEMPERATURE MAPPING USING SSARS	5/30/95																								◇			
B.1	1980-1991 EQUATORIAL WIND FIELD MODEL STATEMENT OF COMPLETION	6/30/93	◆																										
B.2	EXTRACT THE COASTAL KELVIN SIGNAL FROM THE EQUATORIAL MODEL AND DRIVE THE MID-LATITUDE MODEL FROM 1980-1990 AND PROVIDE A VIDEO OF THE SOLUTION	9/30/93				◇																							

GAMOT Deliverable Master Schedule

GAMOT DELIVERABLE MASTER SCHEDULE

Jul 13, 1993

TASK	DELIVERABLE	Start Date	1993							1994												1995							
			J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
B.3	INTEGRATE THE MODEL SOLUTIONS BETWEEN HAWAII AND WEST COAST RECEIVERS AND PROVIDE A GRAPH OF TRAVEL TIME DIFFERENCE AS A FUNCTION OF TIME AND GREAT CIRCLE PATH	9/30/93				◇																							
B.4	DRAFT PAPER (AND PROGRESS REPORT) DEMONSTRATING CONNECTION BETWEEN OBSERVED ACOUSTIC DATA AND OCEAN CLIMATE MODEL	12/30/93							◇																				
B.5	PROVIDE DETAILED PLAN FOR IMPLEMENTING INVESTIGATION FOR MORE COMPLICATED MODELS. PROVIDE PROTOTYPE DESIGN OF EXPERIMENT FOR MONITORING THE NORTH PACIFIC FOR CLIMATE CHANGE AND NATURAL VARIABILITY	6/30/94													◇														
B.6	DOCUMENT RAY TRACING PROGRAMS USED IN OCEAN PHYSICAL MODELING	12/30/94																			◇								
B.7	REPORT ON THE ANALYSIS OF THE RUN OF 1970-1991 NRL MODELS	5/30/95																								◇			
B.8	IMPLEMENT DATA ASSIMILATION PLAN USING ADJOINT MODEL	5/30/95																								◇			
B.9	FINAL REPORT EXPLAINING OR NOT EXPLAINING OBSERVED CLIMATE VARIABILITY IN THE NORTH PACIFIC OCEAN	6/30/95																									◇		
C.1	SSAR PROGRESS REPORT	11/30/93						◇																					

GAMOT Deliverable Master Schedule

GAMOT DELIVERABLE MASTER SCHEDULE

Jul 13, 1993

TASK	DELIVERABLE	Start Date	1993							1994												1995							
			J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
C.2	SSAR DESIGN AND TEST REPORT	4/30/94											◇																
C.3	SSAR UPDATED DESIGN REPORT	3/30/95																						◇					
	SSAR DELIVERIES																												
C.4	TWO PROTOTYPES	8/30/93			◇																								
C.5	SSARs 1 THRU 3	4/30/94											◇																
C.6	SSARs 4 THRU 6	6/30/94													◇														
C.7	SSARs 7 THRU 10	8/30/94															◇												
	CRUISE REPORTS																												
C.8	DEPLOY SSARs 1-3	6/30/94													◇														
C.9	DEPLOY SSARs 4-6	8/30/94															◇												
C.10	DEPLOY SSARs 7-10	10/30/94																	◇										
C.11	SSAR FINAL REPORT	6/30/95																									◇		
D.1	70 HZ SOURCE ASSESSMENT	7/30/94														◇													
D.1	MOORING FABRICATION REPORT	9/30/94																◇											
D.2	AUTONOMOUS MOOR AT SEA TEST AND CRUISE REPORT	1/30/95																				◇							
D.3	MOORING DEPLOYMENT CRUISE REPORT	3/30/95																						◇					
D.4	MOORING MAINTENANCE CRUISE REPORT	5/30/95																								◇			

GAMOT Deliverable Master Schedule

GAMOT DELIVERABLE MASTER SCHEDULE

Jul 13, 1993

TASK	DELIVERABLE	Start Date	1993							1994												1995							
			J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
E.1	DARPA COORDINATION MEETINGS AND PROGRAM BRIEFS	5/20/93 6/7/93 7/1/93 9/16/93 10/7/93 1/15/94 3/23/94	◆◆			◇	◇			◇		◇																	
E.2	QUARTERLY PROGRESS REPORTS	7/15/93 10/15/93 1/15/94 4/15/94 7/15/94 10/15/94 1/15/95 4/15/95		◆			◇			◇			◇			◇			◇			◇			◇				
E.3	FINAL PROJECT REPORT	6/30/95																									◇		
F.1	TRANSITION PLAN IMPACT REPORT	6/30/95																									◇		
F.2	LONG TERM PROGRAM INPUT REPORT	6/30/95																									◇		
F.3	LONG TERM PROGRAM RISK ANALYSIS REPORT	6/30/95																									◇		

GAMOT Deliverable Master Schedule